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An Oversimplified Overview of Undersea Cable Systems

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Will be posted at http://nicewww.cern.ch/~davidw/public/SubCables.html

Background

This short paper has been prepared in order to provide members of the world-wide particle physics community, and network users from other disciplines who might also be interested, with some background material for understanding an area of technology and business which will play an important role in determining how much bandwidth they will be able to use for their wide-area networking over the next 5-10 years. The particle physics community is facing a very significant increase in the volume of data that it must deal with (roughly speaking, up to 1000 times more data in the next decade), and needs to make sensible plans for handling this data, based upon the most probable technology and cost evolution.

It is important to realise that this paper has not been prepared by an expert in undersea cables for an audience of communications specialists, but by a novice in the field for non-specialists. I would like to acknowledge help from multiple sources while I was acquiring information. I hope that there are no major errors of fact or omission, but, if there are, then please inform me so that I can prepare an updated version. One area which is quite difficult to understand is the exact capacity of several of the modern cable systems, since there is often confusion about how much of the bandwidth will be held in reserve to deal with emergency re-configuration, and how much is available for normal service. Any pointers to clear information on that subject would be welcome.

The present business structure

There are three leading suppliers of submarine cable systems world-wide. SSI (Submarine Systems International) is in the process of being "spun-off" from AT&T, where it was AT&T Submarine Systems Inc. It now forms part of Tyco, which is a major American industrial and commercial conglomerate. KDD Submarine Cable Systems is part of the KDD (Kokusai Denshin Denwa) group, which is the dominant supplier of international telecommunications in Japan. Alcatel Submarine Networks was formed several years ago by the merger of the submarine cable interests of Alcatel and the British company STC (Standard Telephones and Cables).

Around these companies we can find a whole undersea cable "supply" industry. Cable and Wireless Marine play a very important role in the business of maritime installation and repair, but the parent company (Cable and Wireless) also has non-negligible interests in infrastructure and communications services. Pirelli seems to be a small(er) supplier of cable systems which would like to grow. Corning Glass, Lucent Technologies and Alcatel are all important suppliers of fibres, and there are probably others. And then there are specialists in all aspects of cable manufacture, route surveys, and cable laying and burial. And we should not forget PTTs around the world, who have often "supplied" and installed their own cable systems when these were on a small enough scale - the Nordic countries are a good example of this.

Traditionally the "supply" industry has installed cable for the "carriers". These were the national PTTs and quasi-PTTs (AT&T, Sprint, MCI, etc.). It has been standard for cables, especially the largest systems, to be planned, financed and operated by carrier consortia, which often had as many as 20-30 members, who participated in the investment in a well-defined way, depending on their foreseen requirement for capacity. The traditional time span between initial planning and a major cable system being ready for service has been some four years, and cables are engineered for a 25-year operational lifetime.

Some important technical issues

Pairs of fibres

Full duplex signalling is used on all present undersea cables, with each optical fibre of a fibre pair transmitting signals in only one direction. The same statement is probably correct for all terrestrial cable systems which are in production, although experiments have certainly been conducted with signalling in both directions down a single fibre. Some people believe that, especially if done at different wavelengths in the opposite directions, this might become standard at some time in the future.

Repeatered and repeaterless systems

If the undersea span which has to be covered is less than about 400 km it is possible to transmit the optical signal(s) down a single fibre (pair), without any intermediate undersea signal processing. Beyond that distance, the signal becomes so attenuated and/or dispersed that it has to be boosted and re-shaped in underwater repeaters, which have to be powered via the cable. This distinction (whether powered repeaters are present or not) is rather fundamental for the engineering design of the cable system, and almost produces two distinct submarine cable sub-industries.

Repeaters are devices which are 100-200 cm long, 30-50 cm in diameter, weigh about 300-500 kg and cost 500-1000 K$ each. They are typically designed for a lifetime of 25 years at up to 7000 meters depth without maintenance, and each one requires about 20 W of power. The design choices made for the repeaters, including the number of fibre pairs that are handled and the amplification characteristics, obviously determine the ease, or difficulty, of making later upgrades to the transmission capacity on an already installed cable, and this is one of the ways in which marine and terrestrial cables differ the most.

Regenerating or optically amplified repeaters

If we confine ourselves to the North Atlantic, all cables laid prior to 1988 were analogue (coaxial). In 1988 the first optical fibre cable (TAT-8) came into operation, with regenerating repeaters which took the incoming (weak) optical signal, converted it to an electrical signal and amplified that, and converted that (strong) signal back to optical form to send along the next stretch of the cable. In 1996 the first cable (TAT-12/13) using fully optical amplification via erbium-doped fibre amplifiers (EDFAs) came into service. These optical amplifiers avoid the need for two signal conversions, and are now the norm. This change from regeneration to optical amplification considerably reduced the number of active components which had to be qualified for 25 years of undersea service, and should have significantly improved the intrinsic reliability of the cable systems (though that is so high that it is difficult to measure - see below).

As far as I can tell the signals transmitted on regenerated cable systems conformed to the PDH (Plesiochronous Data Hierarchy) standard, and those transmitted on optically amplified systems conform to the SDH (Synchronous Data Hierarchy), and I suspect, but am not sure, that this is not an accident. SDH, and the related SONET (Synchronous Optical Network), standards, are now used extensively as the basis for line interconnection, multiplexing, and network monitoring and management in terrestrial telecoms networks, whereas PDH fits in less easily .

Wavelength division multiplexing (WDM)

It has recently become possible to transmit signals at more than one wavelength on each fibre pair. If we regard STM-16 (2.5 Gbps) as the most cost-effective transmission speed in the SDH hierarchy today, then cable systems which are about to go into service can transmit STM-16 signals at four or eight different wavelengths, to give a total capacity of 10 or 20 Gbps per fibre pair. These wavelengths are typically separated by some fraction of 1 nm at around 1550 nm.

From point-to-point cable connections to networks

There is a general trend to integrate modern undersea cable systems intimately into the overall world-wide SDH infrastructure. Cables initially were operated as point-to-point devices. Then they acquired branches, were formed into loop configurations for redundancy, and were designed with multiple drop and insert points. The use of WDM helps in these more complex system designs, since Bragg filters (which are passive optical devices, therefore reliable for undersea operation) can be used to selectively extract and insert one wavelength to or from a side branch onto the main cable. In the industry jargon these devices are OADMs, for Optical Add/Drop Multiplexors (or Branching Units).

Power on repeatered cables

When repeaters are needed they must be powered. The standard approach is to send a constant current of about 1A from one end of the cable to the other, along a copper sheath which lies outside the fibres and inside the armour (if present). Each km of cable offers a resistance of close to 1 ohm, and there is a drop of about 20 V across each repeater, leading to a requirement of close to 10 KV across a typical 7500 km oceanic crossing with 100 repeaters. In branched cable systems the power management becomes somewhat more complex, and the branching units incorporate very high reliability relays to cope with the power reconfiguration needed in case of repairs.

Some of the engineering limits

Many papers presented at the recent SubOptic'97 conference dealt with the topic of the engineering limits which are currently being faced by submarine cable design teams. These address almost all elements of cable systems, including the fibres themselves, where there is a search for a broader effective area and for features, including dispersion management, which will allow better handling of WDM and/or soliton transmission; the laser transmitters; the optical amplifiers; the detection systems; cable and repeater design for more fibre pairs; and signalling formats including improvements in the forward error correction techniques.

Marine factors

The main source of problems with submarine cables comes from external sources such as fishing and anchors, and the damage is either via compression, when a heavy weight hits a cable, or via dragging, and, in the limit, breakage. Anchors from the largest vessels can penetrate the sea-floor by several meters, but present no problem at depths of more than 150 m. Fishing nets, on the other hand, penetrate less deeply, but are operational at depths of up to 1500 m. Since the early 1980s submarine cable has been buried to a depth of typically 1 meter in areas where threats from anchors or fishing can be anticipated, and, indeed they avoid anchorages used by deep-sea vessels as much as possible. The cables are also armoured, typically with one or two layers of high tensile steel strands, when they have to be laid in those areas. Burial, and the use of armoured cable, makes the installation slow and expensive, but seems to pay off well in terms of reliability.

There is a fleet of some thirty more or less specialised vessels used world-wide for submarine cable installation and repair. The largest vessels are not cheap (close to 100 M$ by the time they are ready for sea), but can install many thousands of km of cable (with the repeaters already spliced in) in a single operation. They have several very deep holds which can take a few weeks to fill with the cable - the filling is a manual operation. They can then lay the cable at speeds of about 7 knots (15 km/hour) in the deep ocean, at depths of up to 7000 m. While the position of the ships as they lay the cable is well understood, via the Global Positioning System, the position of the cable on the ocean floor is less well known, owing to a variety of dynamic effects, including motion induced by currents at different depths, as many km of cable drop from the ship. It is important to try to lay the cable with a small (but positive!) amount of slack, since loops or suspensions are very likely to cause subsequent problems via chafing or by being snagged. Closer inshore, ploughing-in of cable can only proceed at speeds of less than about 1 knot, and special care may have to be taken with very rocky marine bottoms, or in the presence of strong currents, which can uncover cables buried deep in sand, and near anchorages or fishing grounds.

Experience indicates that less than 20% of all repairs are in the deep ocean, where the intrinsic faults of the cable system are the major factor, while repairs at depths of less than 1000 m. are mainly due to "external factors". One captain with experience of repair work indicated that one repair every three years might be typical for any given North Atlantic cable, whereas one repair every five weeks would be more normal for a cable crossing the North Sea, where there is very heavy fishing activity and the tides are continually moving the sandy sea floor. SSI's accumulated experience shows that modern cable systems should only need of the order of one repair for internal failures (i.e. not counting external events) during their 25-year planned lifetime.

Major cable systems

TAT-n

Most trans-Atlantic traffic has been carried on a series of cables named from TAT-1 to the most recent TAT-12/13 system, and these cables were planned, installed and operated by carrier consortia. TAT-1 to TAT-7 were coaxial cables, while TAT-8 was the first optical fibre cable on the North Atlantic route.

The different cables often have different landing points. In the USA these are spread along the eastern seaboard, while in Europe they are typically in Brittany, the West of England, and in Northern Germany. Today TAT-8 through TAT-12/13 are all in service. The typical price for a complete system (cables, repeaters, equipment at the landing points, all marine operations) is about 600 M$.

TAT-8 connects Tuckerton NJ to England and France and has offered (2+1)*280 Mbps PDH capacity since it came into operation in 1988. [The convention (2+1)*280 used to describe the capacity indicates that two 280 Mbps channels are available to provide the normal service, while one 280 Mbps channel is available for back-up purposes. I believe that each of these channels occupies one fibre pair, but I am not completely sure. This was a footnote originally, but the .html version of the paper seems to lose footnotes, which is why it is now placed here]. In the initial forecasts made by the consortium it was expected that the TAT-8 capacity would be filled by the year 2000, but it was actually filled in 1990, six times faster than foreseen.

TAT-9 and TAT-10 both came into operation in 1992, each offering (2+1)*565 Mbps of PDH capacity. TAT-9 links Manahawkin NJ and Nova Scotia to Spain, France and England, while TAT-10 links Green Hill RI to Germany and Holland.

TAT-11 came into operation one year later, again offering (2+1)*565 Mbps PDH from Manahawkin to England and France.

TAT-12 and TAT-13 should be considered in some sense as a single unit, since they operate as a fully backed-up cable system, offering (2+2)*5 Gbps of SDH capacity between Green Hill and Shirley NY, and England and France. They use EDFA optical amplifiers with a repeater separation of about 45 km and when they entered service in 1996 they offered a major boost in capacity on these routes. The TAT-12/13 system, with an operational capacity of the 10 Gbps, provides almost 60% of the total cable capacity available on the North Atlantic today. This TAT-12/13 capacity is now believed to be 100% subscribed for, even if it is probably not yet being fully exploited I have been told that there are plans to upgrade the capacity on this cable system over the next two years by a factor of two, in two stages, by installing WDM equipment, but I have not found any published information about this. There are also rumours about a TAT-14, but again there seems to be nothing published.

PTAT

As far as I can tell this cable, entering service in 1990, and offering (3+1)*140 Mbps PDH capacity between Manasquan NJ, Bermuda, Ireland and England, is technically very similar to its TAT relations of similar age. The name PTAT, for Private TransAtlantic cable system, indicates that it was planned and financed, and is operated, by a private group (Cable & Wireless, Mercury and Sprint), rather than by a traditional carrier consortium.

CANTAT-3

This cable, which runs from Nova Scotia via Iceland and the Faroes to Northern England, Denmark and Germany, came into operation late in 1994. It offers (2+1)*2.5 Gbps of PDH capacity, and represents a significant fraction (some 25%) of the total North Atlantic capacity at this time. Teleglobe Canada is the dominant owner, but I believe that the management is formally via a normal carrier consortium. While searching on the Web, I discovered that Teleglobe paid for its (major) share of CANTAT-3 out of its operating budget in 1994 and 1995!

Columbus

Columbus-2 runs from Italy, via Spain and Portugal, to West Palm Beach FA and Mexico. It came into service at the end of 1994, offering 2*2.5 Gbps of SDH(?) capacity on a two fibre pair cable with optical amplifiers. It is some 11,000 km long and the initial cost was 345 M$. As far as I understand, backup for the Europe to USA part of the cable comes via satellite. Just before the system was put into service, successful tests of 4-way WDM were carried out on a 2000 km section, giving 2*10 Gbps of capacity, but this was not used in production. It was recently (March 1997) announced that additional capacity had been activated on Columbus-2, but no details were given.

In April 1997 plans were announced for Columbus-3. This should come into service in July 1999 and connect a similar set of countries to those involved in Columbus-2, seemingly without Mexico, at a cost of some 300 M$ and with an initial design capacity of 10 Gbps, expandable to 40 Gbps, on a twin fibre pair cable.

TPC

TPC-4 (Trans-Pacific Cable 4) came into service in 1992, offering (n+m)*560 Mbps of capacity between Japan on the one side and Vancouver Island and Manchester CA on the other side of the Pacific Ocean. I believe that n+m is probably 2+1, and that this is PDH capacity.

TPC-5CN (for Trans-Pacific 5 Cable Network) is a major system which has just come into service across the Pacific. I think that it offers (2+2)*5 Gbps in a fully backed-up configuration similar to the TAT-12/13 arrangement. The northern cable links Japan to Bandon OR, while the southern route links San Luis Obispo CA to Hawaii, Guam and Japan. Tests have been carried out to see if this cable can be upgraded by the use of at least two-way WDM. These were positive, especially on the northern route, but not yet fully convincing on the southern route.

FLAG

FLAG, for Fibre Link Around the Globe, does not, at the moment, actually go around the globe, but rather links Europe to the Middle East and Asia. It is not a traditional carrier consortium, but is mainly funded by "private" investors, including Dallah Al Baraka group (Saudi Arabia), Marubeni Corporation (Japan), Gulf Associates (USA), Telecom Holding (Thailand) and the Asia Infrastructure Fund (Hong Kong), with Nynex (one of the Baby Bells) as the "managing sponsor". It will run 27000 km from England, where it shares the same landing station as Gemini (see below), to Japan, with 15 powered landing points in 12 countries, and offers (I think) (2+2)*5 Gbps SDH capacity. It crosses Egypt and Thailand via dual redundant terrestrial routes. The landing in Shanghai will be the first Chinese cable landing station.

Its total cost is given as 1200-1500 M$, and it is expected to come into service in September 1997.

SEA-MEA-WE

The SEA-MEA-WE cables also link South East Asia, the Middle East, and Western Europe, but they are owned and operated by traditional carrier consortia.

SEA-MEA-WE2 came into service in 1994, offering probably (2+1)*560 Mbps of PDH capacity on a long route between Marseille, Italy, Djakarta and Singapore. The repeaters are electrical regenerators spaced roughly every 130 km.

SEA-MEA-WE3 is due to come into full service in March 1999. It will run from England via the Mediterranean to India, Indonesia, Australia and Japan, with a total of some 40 landing points in 34 countries, and a total length of 39000 km. It will initially offer a total of 20 Gbps of SDH capacity, using 4-way WDM multiplexing on two fibre pairs running at 2.5 Gbps per wavelength, but with the potential to increase the capacity to 40 Gbps by using 8-way WDM.

The total cost is indicated as being similar to that for FLAG. The system for selling capacity to consortia members is not completely traditional, although the resulting prices still seem to be rather high. From Europe to Japan a 2 Mbps channel could be purchased by the consortium carriers for a one-time charge of 1200 K$. On the same route an STM-1 (155 Mbps) channel would therefore require an investment of some 90 M$, which is interesting to compare with the Atlantic Crossing and Gemini pricing (see below, under New Players in the Market) - but be careful, it is not easy to make a fair comparison between those very different systems!

Africa One

There has been considerable discussion about and publicity for a project, mainly initiated in the ITU, to install an undersea cable system around Africa. This would be the Africa One cable system, with a total length of 39000 km and a likely cost of some 1600 M$. As far as I can judge this project is stalled at the moment, and does not look likely to proceed in the near future.

Many others

There are an enormous number of other cable systems which would have to be covered in any listing aiming at completeness. There are systems going to essentially every island in the world, and also criss-crossing places such as the North Sea and English Channel, the Caribbean, the South China Sea, and connecting Australia and parts of South America.

Technical and commercial evolution

Time to market

One of the most obvious changes which is happening at the moment is that the very relaxed pace at which the traditional carrier consortia operated is being dramatically challenged. There used to be at least four years between the initial consortium discussions about a new cable and its introduction into service. FLAG, which is a very complex cable system, aims to reduce this to 27 months, and looks to be on schedule. In a rather simpler technical and organisational environment, Gemini (see below) aims to be in service on one of its routes just 15 months after contract signature, with the other route following 6 months later, and Atlantic Crossing has an even more aggressive schedule.

Transmission speed at a given wavelength

Today's systems use 2.5 Gbps as the "standard" SDH interface at the end stations. The next obvious step up would be to move to 10 Gbps in the SDH hierarchy, but this requires expensive and specialised electronics, and seems to represent rather poor price-performance and flexibility at the moment. But the technology is available for use when needed. Experiments have been reported with soliton transmission at 20 Gbps over 200 km (KDD) and at 20 Gbps over many thousands of km (by looping) (Alcatel).

More wavelengths

It appears that a number of factors which limit the number of wavelengths which can be transmitted on a single fibre (pair), such as the optical gain in the EDFAs, dispersion compensation, and the modulation technique (RZ or NRZ), should be amenable to improvement. For systems being installed or planned today, 4-way or perhaps 8-way WDM can be considered, but serious lab tests have been reported with transmission at 20 (SSI), 22 (KDD), 24 (Fujitsu), and 32 (SSI) different wavelengths over thousands of km.

More fibres per cable

"Normal" optical fibre costs about 0.1 $ per metre to fabricate, and retails in the region of 0.2-0.25 $ per fibre-metre when several fibres are installed in a cladding, unless there are few fibres and the cladding is very exotic. So, a 16-fibre indoor cable might cost 4 $ per metre. Double armoured submarine cable can cost in the region of 20 $ per metre, but, until very recently only contained two fibre pairs. The "standard" has recently moved to four pairs per long-distance cable.

The limit to the number of fibre pairs in a submarine cable does not come from the cost of the extra fibres, but from the economics of building repeaters. These are very expensive devices (because they have to be very reliable in an inhospitable environment), with a very limited production run. A significant part of their costing depends linearly on the number of fibres that has to be amplified. If and when the industry becomes convinced that building repeaters to handle 8 or even 16 fibre pairs is an investment which makes economic sense, then such an upgrade could happen quite quickly.

More pure optical switching

As submarine cable routes become even more integrated into the world-wide telecoms infrastructure, it will become tempting to try to retain the signals in pure optical form, rather than converting them back and forth for electrical treatment. Optical cross-connects and (de)multiplexors could improve cost-performance in the interface equipment at the landing stations.

Summary

The highest capacity that I have heard being discussed for a commercial repeatered system is the 40 Gbps of service capacity that will be offered on Atlantic Crossing, which should come into service in 1998. Given the serious demonstrations of up to 160 Gbps per fibre pair on long distance lab systems, we can safely predict that by the year 2000 people should be in the process of installing repeatered cable systems with a total capacity of at least 160 Gbps.

At a recent major industry conference, speakers were willing to treat the idea of cable systems with total capacities of 1 Tbps and installable by the year 2005, as worthy of serious speculation.

Costs and cost evolution

Time to fill capacity

When TAT-8 was planned the consortium estimated that it would take twelve years, or half the planned lifetime, for it to be filled. It entered service in 1988 and was full two years later. The TAT-12/13 cable system offered twenty times more capacity than TAT-8, and the consortium again estimated that twelve years would be needed before the capacity would be filled. The system entered service in 1996, the capacity is already subscribed for, and will surely all be in use by the end of 1998.

The situation in the Pacific region with TPC-4 and TPC-5 is similar, although not quite so dramatic.

Return on Investment

It is hard to avoid the conclusion that almost all existing cable systems must have offered an extremely high rate of return on investment, in the range of 30-50% per annum. Of course, it is difficult to be absolutely sure of this without having been privy to the accounts of the consortia, but most systems must have fully paid off their investment within a maximum of three years after coming into service, and then have produced a large and steady revenue stream for many years afterwards.

Of course, the very large profits being made on international leased circuits may have been accounted to the individual carriers, rather than to the cable consortia, but the overall profits were certainly very large. To give one example, a 2 Mbps circuit from Switzerland to the USA has been retailing to end-users recently at about 500 K$ per year, while the consortium purchase price, discounted over five years and including annual maintenance and operation, must have represented only some 60 K$ per year. Even allowing for the terrestrial circuits and for operations, overheads and profits, it can be seen that this has been, and still is, a very lucrative market.

Lifetimes

Given the rapid progress in transmission capacity which we can expect to see over the next 4-8 years, modern optical fibre systems risk to become economically obsolescent well before their planned 25-year lifetime. This is because any new cable system coming into service is likely to have a similar cost, but five to ten times the capacity, of a system which is 5 years older, and therefore to be able to offer capacity at a correspondingly lower price. This is very similar to the environment in which the computer market has operated for the past forty years.

Terrestrial cable systems

As far as I can understand it is neither much simpler, nor much quicker, to install a major terrestrial cable system rather than a submarine system. Back of envelope calculations indicate that the overall pricing of a complete terrestrial system should be about 3-4 times cheaper than for a submarine system of comparable length. However, once they have been installed, there are three significant differences. You can typically reach any spot on a terrestrial system in order to carry out repairs within a few hours, whereas you might have to wait many days, even in good weather, for the nearest cable repair ship to deal with a difficult mid-ocean repair. The terrestrial system is also likely to have some 50 times more capacity than the submarine system, because many more fibre pairs will have been installed in the cable. And the terrestrial system can almost certainly be more easily upgraded to take advantage of advances in optics and electronics.

The end of the 2Mbps barrier?

Consortia have traditionally sold capacity on cable systems in units of MIUs (Minimum International Units?), which were 2 Mbps channels. And there have been complex rules about who could purchase such capacity (with a strong preference going to consortium members) and how it could be re-sold. This practice has been at the origin of the fact that the price of trans-oceanic bandwidth has shown no economy of scale above 2 Mbps. While trading 2 Mbps units may have made sense when the cable capacity was 280 or 565 Mbps, and the traffic was almost entirely voice, it makes little sense on cables with 10-40 Gbps of capacity. For end-users who need to transmit large volumes of data, and who have been faced with linear pricing on the ocean routes, the end of MIU pricing regimes will be very welcome.

Will the traditional carrier consortia survive?

No industry changes overnight, but it seems clear to me that the submarine cable industry is entering a period of very rapid transition. Data traffic has recently started to use more capacity than voice traffic (including fax) across the North Atlantic. With the demand for bandwidth exploding, with the price of providing that bandwidth dropping fast, and with the need for fast business decisions concerning large investments, we might well expect significant restructuring of the industry. It will no longer be about providing telephone circuits, but about providing bandwidth. Rather than consortia of carriers we are seeing the emergence of groupings of major investors which decide which cable systems should be built, with what capacity, and at what time. Of course, those investors will need the expertise of the existing "supply industry" to install and operate the systems, and to carry out the R&D needed to increase the transmission capacity. They probably expect to be able to sell their cable capacity to a mixture of traditional "carriers" plus new Internet Service Providers and maybe even directly to large companies. How successful they will be, and where the traditional consortia will fit in to this scenario, is difficult to predict. And we should all remember that predictions in the computing and telecoms industry have always been notoriously unreliable

New players in the market

FLAG

FLAG has been discussed above, since it should come into service within a few months, but it is mentioned again here, since it is a strong example of the arrival of new investors in the market to install and operate submarine cables.

Gemini

Gemini was the first example of a major move in the North Atlantic market. It will be a twin cable system connecting two landing stations near New York (Manasquan and Greenhill) to two landing stations in England, with terrestrial connectivity ("back-haul") to New York and London already foreseen. The first cable is due to come into service in March 1998, only 15 months after contract signature, and the second in October 1998, and, when completed, will offer, as far as I can understand, 20 Gbps of high-reliability SDH capacity.

The shareholders are MFS Worldcom and Cable & Wireless. MFS Worldcom was formed when Metropolitan Fibre Systems (MFS) and Worldcom merged at the end of 1996. MFS is mainly in the business of providing fibre-based communication services to the financial communities in major city centres. In conjunction with Alcatel, MFS cabled up much of Paris (via the sewers) in a 12-month period between May 1995, when MFS obtained a license for this, and May 1996, when the first customers were connected. Worldcom is the fourth largest long-distance phone company in the USA (after AT&T, Sprint and MCI). They have announced that they intend to install a pan-European telecoms infrastructure.

The Gemini system is being built by Alcatel Submarine Networks, with Cable & Wireless doing most of the marine work.

Atlantic Crossing

At the end of March 1997 another competitor declared its intention to compete on the North Atlantic route. SSI, together with Global Telesystems ("an investor-owned company sponsored by the Pacific Capital Group"), will build a twin cable system called Atlantic Crossing between Brookhaven NY and England and Germany. The connection to England is due to enter service in May 1998, and the loop should be completed via the German landing station in November 1998. When completed this system will offer 40 Gbps of capacity using 4-way WDM at 2.5 Gbps per wavelength over four fibre pairs.

My assessment is that this is a very serious project, with very interesting pricing. Basically Atlantic Crossing intend to only sell capacity in units of STM-1 (155 Mbps). With purchase of the first such unit costing about 8 M$ and annual maintenance and operation costs capped at a maximum of 250 K$, the five year amortised cost of such an STM-1 circuit is under 2 M$ per year, corresponding to some 25 K$ per year for a 2 Mbps circuit.

This is about a factor 2.5 below the TAT-12/13 pricing for consortium members. However, one problem that they will have to face is that, unlike the case of Gemini and Worldcom, they do not yet have a preferred partner to worry about the provision of the pan-European infrastructure which could connect potential customers such as the smaller Internet Service Providers in Europe to the landing stations at sensible costs.

Summary and tentative conclusions

The intention of this paper is more to provide information than to reach conclusions. Complementary information concerning the status and likely evolution of the other technologies which are important for international networking, such as satellites and terrestrial cabling, would, in any case, be needed before trying to reach any definitive conclusions.

My personal and very tentative conclusions are:-

- Submarine cable supply is a rather impressive high-tech business.
- There is plenty of scope, on technical grounds, to expect strong improvement in cable capacity at roughly constant cost over the coming decade.
- It is hard to believe either that the prices charged at present for international data circuits are "cost-based", or that end-users have seen anything like the full benefit of the improvement in the price-performance of cable systems that has taken place in the past decade.
- It must have been very profitable to have a share in the ownership of submarine cables during that time.
- Fundamental changes are now taking place in the structure of the industry. They are driven by the growing importance of data as opposed to voice in international telecoms, by growing de-regulation, and by the arrival of investor-led consortia rather than the traditional telecoms consortia.
- It is very difficult to predict how quickly and how strongly these changes will feed through into significantly lower end-user prices for international data networking.

Sources of further information

A good introduction and overview, which should be easy to obtain, is "Lightwave Communications, the Fifth Generation" by Emmanuel Desurvire, then at Columbia, and now with Alcatel Research. This is in the January 1992 Scientific American. There are also many articles with interesting titles in the January/February 1995 edition of the AT&T Technical Journal (Vol 74 No 1), but I do not have a copy of this, and I was rather disappointed with one overview article which I have seen.

The best detailed source of information on the scientific and engineering aspects of undersea cable systems seems to be the proceeding of the SubOptic'97 conference. This is the reference conference for this industry, and it is held every four years. However, those proceedings are probably expensive to obtain.

Papers have also appeared in a number of journals and conference proceedings, such as IEEE Photonics Tech. Lett., IEEE Lightwave, Optical Fiber Communication (a conference series), etc.

There is a large amount of information available on the Web, and this is probably the best source of information about industry developments and new cable systems, but there is also some very good information about fibres, signalling, and optical amplification. I hope soon to post some of by bookmarks on the Web as a way of giving people some starting addresses.